SURGERY OF VENTRICULAR SEPTAL DEFECTS*

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Direct surgical repair of most defects within the heart has become almost a mundane occurrence. Its rapid growth to maturity has been fostered by many pioneers, of whom we acknowledge Alfred Blalock, Sir Russell Brock, John Gibbon, and Walton Lillehei. These are just a few of the dynamic leaders among hundreds who by faith, hard work, and research have created the method of intracardiac surgery utilizing extracorporeal circulation and cardio-pulmonary bypass.

Although the prognosis for small septal defects is excellent and the disability trivial, there is general agreement that, if the shunt is significant, survival into adult life is unusual. Death occurs from heart failure, endocarditis, or respiratory complications. Heart failure is due to an excessive mechanical work load imposed on the heart by the shunt itself or by progressive endarteritic obstruction of the pulmonary arterial fields in response to hypertension. There is a wide variation in pulmonary arterial resistance from case to case.

In most cases ventricular septal defects are amenable to surgical closure and cure. The risk involved varies with the type and severity of the disease and the surgical skills available.

Material and Management

This brief presentation is confined to specific problems affecting recovery in 37 uncomplicated cases of ventricular septal defect which have been submitted to surgery at the Royal Prince Alfred Hospital since December, 1957. There were 22 males and 15 females, ages ranging from 3 to 32. Methods now used have evolved in the light of this experience.

Pre-operative Management.—All patients are digitalized pre-operatively and the dosage is maintained during the post-operative period. Routine nasal swabs are taken pre-operatively. Cases found harbouring resistant staphylococcal strains are discharged under treatment with local neotracin for three months before readmission. Patients with penicillin-sensitive strains without open skin lesions are submitted to operation under routine antibiotic cover. This consists of erythromycin and chloramphenicol (30 mg./kg./day of each).

Anaesthesia.—A narcotic and atropine are used for premedication. Induction is performed with 2.5% thiopentone sodium, and anaesthesia is maintained with nitrous oxide and oxygen. Muscular relaxation is

obtained with tubocurarine and ventilation is controlled mechanically. During the period of extracorporeal circulation the lungs are held moderately inflated with air and complete paralysis is ensured by intermittent administration of succinylcholine into the arterial line of the pump. At the end of the operation complete reversal of tubocurarine is ensured with atropine and neostigmine.

Perfusion Data.—The systemic arterial pressure, the superior and inferior caval pressures, and the electrocardiograph are monitored throughout operation using a multi-channel recorder, electronics for medicine. Knowledge of the superior vena cava pressure is vital. Adequate perfusion was thought to be 2.2–2.4 litres per square metre of body surface per minute (Kirklin *et al.*, 1957a, 1957b). Delivery of this adequate flow to maintain optimal arterial and venous pressures has not always been technically possible owing to difficulties in matching the lumina of cannulae and the vessels of the patient. An arterial pressure of 70–80 mm. Hg and a venous pressure not more than 10 mm. Hg above the pre-operative level have been regarded as optimal. Extracorporeal circulation was maintained by the Mark vertical screen pump-oxygenator until recently, when a change was made to the Melrose rotating drum oxygenator. Gaseous exchange was accomplished with a mixture of humidified 97.5% oxygen and 2.5% carbon dioxide delivered into the oxygenator at a rate of 20 l./min. Heparin, 3 mg./kg. body weight, was used as the anticoagulant. Neutralization at the end of perfusion has been affected by protamine sulphate.

Operative Technique.—The heart was exposed through a midline sternal split incision (Gerbode *et al.*, 1958). Elective cardiac arrest has been carried out in all but one case. Potassium citrate, 2.5% in heparinized blood (Melrose *et al.*, 1955), was used initially but discarded 18 months ago in favour of intermittent aortic occlusion (Cooley *et al.*, 1958). The periods of occlusion have been limited to three minutes and release periods to 15 seconds. Over the past two years the atrium has been vented during bypass by means of a small incision in the left atrial appendix. This is ligated on completion of the operation when the left ventricle is beating satisfactorily. The defect was closed by direct suture in 21 cases and by an "ivalon" or woven "teflon" patch in 16. 2/0 "dekanatel" sutures on $\frac{1}{4}$ circle taper-pointed needle were used. The patches were fixed to the margins of the defect with interrupted sutures. In the critical postero-superior angle between the aortic ring above and the margin of the septal defect below, where the conduction bundle is vulnerable to trauma, the sutures were placed to the right of the margin parallel to the path of the bundle. The atrial and ventricular wounds were closed by 2/0 "mersilene" sutures on 30-mm. half-circle round-bodied needles.

At the end of the perfusion, before removal of the arterial cannula, blood was transfused from the machine in small increments until the arterial pressure approximated the preperfusion level and the venous pressure equalled or exceeded by 5 mm. Hg the preperfusion level.

Post-operative Management.—Adequacy of blood replacement was estimated at the end of the operation by considering: (a) the total weight of blood lost, (b) the pre- and post-operative weights of the patient, (c) the pre- and post-operative blood volumes estimated by radioactive chromium-tagged cells, and (d) the arterial

*Read in the Section of Cardiothoracic Surgery at the Annual Meeting of the British Medical Association, Auckland, New Zealand, 1961.

and venous pressures. Blood-pressure, venous pressures, and electrocardiogram were monitored continuously for at least 24 hours in the post-operative period. The blood-pressure was maintained by blood replacement in accordance with the measured post-operative loss. Noradrenaline has not been found necessary in this particular group of patients. Arterial blood pH estimations were done immediately post-operatively and four hours later. Intravenous sodium bicarbonate has been given occasionally for metabolic acidosis. Pleural drainage tubes were removed on the first or second post-operative day, when the lungs had expanded and the drainage ceased.

Pathology

Of the 37 cases with mild or absent pulmonary stenosis, the vascular resistance was below 5 units and the mean pulmonary artery pressure below 33 mm. Hg in 23, and above this figure in 14. In 23 cases the symptoms varied from mild to severe. The average ratio of pulmonary to systemic flow was 2.5:1. A history of previous bacterial endocarditis was present in three.

The septal defects varied in size from 0.75 to 2.5 cm. in diameter, the circumferential margin being described as fibrous in 21 and muscular or non-specific in 16. The defect was high up under the aortic root except in one case in which there were multiple deficiencies in the muscular septum and in three cases where the shunt occurred predominantly into the right atrium.

In 11 cases (one with a large traumatic muscular defect) there were associated congenital abnormalities: (a) five with mild degree of pulmonary stenosis (four infundibular, one valvular); (b) three with left superior venae cavae; (c) two with persistent ductus arteriosus; and (d) one with a large abnormal branch of the right coronary artery crossing the anterior surface of the right ventricle towards the septum.

Results of Operation

Mortality.—There were nine deaths in the series, an incidence of 24% (Table I). The mortality can be related to the pre-operative vascular resistance and mean arterial pressure in the lung. In the group with low resistance and low pulmonary artery pressure there were four deaths due to acute or chronic heart failure, pulmonary collapse, haemorrhage, and air embolism

TABLE I.—Comparison of Mortality in Relation to Pulmonary Vascular Resistance

No. of Cases	Resistance	Mean Pulmonary Artery Pressures	Deaths	Mortality
23	Below 5 units	Below 35 mm. Hg	4	17.4%
14	Above 5 "	Above 35 " "	5	36%

TABLE II.—Pulmonary Vascular Resistance and Cause of Death in the Hypertensive Group

Cases	Age	Pulmonary Resistance	Cause of Death
1	4	15	Heart failure, pulmonary collapse
2	3	15	Heart failure, pulmonary collapse, multiple septal defects
3	5	13	Heart failure, pulmonary collapse, cardiac tamponade
4	3	11	Ventricular fibrillation—sequel to division of abnormal coronary artery
5	4	5	Cerebral hypoxia—sequel to superior vena cava obstruction

respectively. All four deaths followed technical errors, mostly multiple and largely preventable, so that in this group there should be a considerable safety margin. Some survived complications that might well have been fatal in the presence of a high pulmonary resistance. In the pulmonary hypertensive group there were five deaths, four partly but not entirely due to the high vascular resistance (Table II).

Cardiac Arrhythmias

Cardiac arrhythmias formed an important group of complications. Their incidence could be related to the type of elective cardiac arrest employed. During operation a total heart-block developed in two cases, and potassium citrate had been employed in both. This 5.5% incidence contrasts with the 28% incidence seen by us in the repair of the tetralogy of Fallot.

TABLE III.—Comparison of Complications in 37 Cases After Elective Cardiac Arrest

Method	No. of Cases	Arrhythmia	Congestive Heart Failure
Potassium citrate	16	Ventricular fibrillation, 5; paroxysmal tachycardia, 1; heart-block, 2	8
Anoxic ..	20	Ventricular fibrillation, 1; partial heart-block, 1	1
No arrest	1		

The first instance of total heart-block followed an episode of cardiac distension and ventricular fibrillation. It was temporary and reverted spontaneously. The patient died 12 hours later with heart failure and pulmonary oedema, and at necropsy there were three residual defects in the muscular septum.

In the other instance the block persisted. At operation a malleable insulated wire electrode was inserted into the ventricle and brought through the skin to a pacemaker apparatus (Weirich *et al.*, 1958). The latter was set at the lowest voltage needed to drive the heart and at the rate required to maintain the blood-pressure at pre-operative levels. It was switched off periodically and sinus rhythm reappeared after 48 hours.

Post-operative heart-block occurred as a terminal event in three patients dying from heart failure. Such instances have been thought to be part of a low-cardiac-output state with resultant tissue hypoxia (Boyd *et al.*, 1959).

Post-operative Bleeding

This gave concern in the early post-operative cases and was related closely to the presence of residual heparin in the blood-stream. At that time the neutralizing dose of protamine sulphate was determined by a titration technique (Perkins *et al.*, 1956). Since this method was abandoned and a dose of protamine twice that of the heparin dose administered, the problem of bleeding had decreased to negligible proportions. Of the 14 instances with a 24-hour post-operative blood loss exceeding 500 ml., 6 occurred in the first 10 cases.

In one case bleeding restarted after early haemostasis. A sample of blood taken at this time clotted, but 20 minutes later fibrinolysis could be demonstrated. The oozing ceased after an infusion of 5 g. of fibrinogen. Apart from this case fibrinogen levels have not been shown to be abnormal.

The blood platelets in the donor blood have fallen to the region of 160,000/c.mm. by the time of perfusion and to the region of 100,000/c.mm. at the end of

perfusion. They have risen to normal levels over the next 12 hours and their deficiency has not been a cause of bleeding.

Wound Infection

The precautions governing the sterility of the heart-lung machine, the detection of likely staphylococcal carriers, and the standard antibacterial cover given against infection appeared to have been adequate. There were four cases of wound infection—three major and one minor. The pre-operative nasal swab revealed no growth in three and a penicillin-sensitive staphylococcus in the remaining case. All four were cured conservatively.

Non-infective Pulmonary Changes Interfering with Respiration

These have been a problem in all cases. Tachypnoea was reported specifically in 19. The post-operative temperature has varied from 100 to 104° F. (37.8 to 40° C.), reaching a peak on the third day and subsiding over the next few days. Of 12 patients with extensive pulmonary collapse, six died. Post-operative x-ray films have revealed diffuse infiltrations in lung parenchyma, most pronounced at the site of internal impingement of the chest drainage tubes. This picture differs from the classical segmental distribution of post-operative collapse. At necropsy on some cases dying after bypass operations the lungs were extremely congested, with the alveoli filled with fibrin and red cells. Minor degrees of these changes may account for some post-operative infiltrations.

Tracheostomy was of great value in children and uncooperative adults. It permitted a sufficient bronchial toilet and the delivery of high concentrations of oxygen into the trachea. A 24-hour period of controlled respiration proved life-saving in a child with severe pulmonary oedema. Great care is necessary in using I.P.P. respiration in patients with severe pulmonary hypertension, as profound falls of cardiac output may result.

Follow-up

In the 28 survivors the defect remains clinically closed in 27. A small leak is still present in one case closed by suture. In one case pre-operative pulmonary hypertension has increased and in another pre-operative staphylococcal endocarditis has recurred intermittently, but appears cured. The cardiac rhythm has remained normal in all cases save one, in which there was a bout of ventricular tachycardia three months after operation. This reverted with procainamide and has not recurred.

Summary

Thirty-seven cases of uncomplicated ventricular septal defect have been repaired with the aid of the extracorporeal circulation at the Royal Prince Alfred Hospital since December, 1957.

There was a 24% mortality, the greater proportion of deaths occurring in the pulmonary hypertensive group.

Overall management and operative findings are outlined. Elective cardiac arrest was employed in 36, potassium citrate causing more frequent arrhythmias than intermittent aortic occlusion.

Twenty-one defects were sutured directly, 16 patched.

Post-operative features including heart-block, bleeding tendency, pulmonary complications, and infection are discussed.

In 27 of the 28 survivors the defect remains clinically closed.

Dr. V. J. McGovern was responsible for the pathological investigations and Dr. H. Kronenberg for the haematological studies.

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CONGENITAL TRICUSPID STENOSIS

A CASE TREATED BY OPEN OPERATION

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Although tricuspid atresia (complete absence of a tricuspid valve orifice) is common, congenital tricuspid stenosis is less well recognized. This paper describes the clinical, laboratory, and operative findings in a child with congenital tricuspid stenosis and an atrial septal defect. Dilatation of the tricuspid orifice was performed with closure of the atrial septal defect, and great clinical improvement resulted. We have found no previous reference to the surgical treatment of congenital tricuspid stenosis.

Case Report

The patient, a girl aged 9, was referred to St. Thomas's Hospital by Dr. P. G. Todd. She had been cyanosed and short of breath since birth. In the first year of life she had been a slow feeder and was said to have become very blue and to have lost consciousness on two occasions. She did not walk until the age of 2, but never squatted. On examination she was normally developed. There was central cyanosis and clubbing equal in the upper and lower halves of the body. The pulse was regular and the blood-pressure 105/80 mm. Hg. There was an "a" wave of 2 cm. visible in the jugular venous pulse. The apex beat was in the fourth left interspace just outside the mid-clavicular line, and its character suggested mild left ventricular hypertrophy. A systolic thrill and murmur were detected to the left of the lower end of the sternum. No diastolic murmur was heard. The second sound in the pulmonary area was finely split on inspiration, the later component not being accentuated.

A chest x-ray film (Fig. 1) showed diminished lung vascular markings but no cardiac enlargement. The electrocardiogram (Fig. 2) showed an rS pattern in V4R and V1 and an R wave of 14 mm. in V5. The P wave in lead II was 2.5 mm. Vectorial analysis showed a mean QRS axis of minus 15 degrees. The E.C.G. was regarded as within normal limits, but the position of the axis raised the possibility of left ventricular preponderance and the prominent P waves right atrial hypertrophy.